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Original Research Article

Study of Hydraulic Coefficeients of Skim milk for Designing of Skim milk Processing System

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Skim milk, Hydraulic coefficients, Coefficient of velocity, Coefficient of discharge and Coefficient of contraction

A B S T R A C T

The present investigation was to determine the hydraulic coefficients of skim milk with respect to time and temperature. These hydraulic coefficients were determined considering three levels of temperatures 25, 30 and 35°C at intervals of 0, 1, 2 and 3 h. The highest values for coefficient of velocity, coefficient of discharge and coefficient of contraction of skim milk were observed 0.94, 0.77 and 0.82 at 35°C respectively and with respect to time it was observed 0.91, 0.72 and 0.79 at 0 h respectively. There is not much appreciable effect of variation on hydraulic coefficients with respect to time, whereas the temperature had shown significant effect ($P<0.05$) on hydraulic coefficients of skim milk. The data generated in the present investigation can be utilized as guidelines for designing of skim milk based processing systems like evaporated plant and skim milk spray drying plant etc.

Introduction

Dairying in India has played a predominant role in up-gradation of socio-economic conditions of the people. The milk revolution in India reveals an exceptional success story as reflected by increased milk production from 17 million tonnes in 1950-51 to 155.49 million tonnes in 2015-2016 (Nandkumar, 2016). India has maintained first position in milk production since 1998 with milk production of 74.1 million tonnes per annum, overtaking the United States. In 2015-16 milk production of India produced approximately 18.5 per cent of the world's total milk production. India's estimated demand for milk is likely to be about around 200 million tonnes in 2021-22 (www. nddb.org). Skim milk is a by-product obtained during the manufacture of cream. It is rich in solid-not-fat content and has high nutritional value. In dairy plants, it is mostly utilized either in standardization for the manufacture of main dairy products or preserved by removing moisture in spray dried form. It is regarded as a by-product only when it is either not economically utilized or utilized for desired by-products like casein co-precipitates, protein hydrolysates etc (Gupta, 2008). By-product from skim milk is casein which is utilized for the manufacture of imitation of cheese. From total production of skim milk casein about 20% of demand is for nutraceutical. The co-precipitates from skim milk have several advantages like increased yield and higher nutritional value over that of casein. Milk protein hydolysates of skim milk find extensive use in nutritional, dietetic and formulated foods, where a pre–digested from a protein is needed (Kumar, 2016). The flow property does not only affect quality, it is also important in plant and process design. Heat transfer and pasteurization may be incorrectly evaluated if the actual flow properties are not assessed (Rao and Anantheswaran, 1982). Knowledge of flow properties of food products is important for design and process evaluation. In addition, the characterization of food system is important to establish relation between flows and correlate physical parameter with sensory evaluation (Figoni and Shoemaker, 1983). Flow behavior of food products has a tremendous importance since these properties are determinant factors in equipment design, quality control and unit operations such as pumping, homogenization, blending, cooling, pasteurization, sterilization, evaporation and dehydration etc.

Materials and Methods

Preparation of skim milk

The skim milk was procured from Chhattisgarh State Cooperative Dairy Federation, Raipur. Skim milk was obtained as a by-product in the manufacture of cream from whole buffalo milk using centrifugal cream separator. Initially milk was collected from chilling centers at below 5^{o}C, followed by preheating to 30-40^{o}C then the milk was pumped to centrifugal cream separator for separating the milk into skim milk and cream. Followed by heating skim milk to 80-90^{o}C. The heated skim milk was cooled to 5^{o}C and was bought to College of Dairy Science and Food Technology, Raipur.

Procurement of skim milk

The skim milk (about 70 to 80 L) which was been procured at afternoon time and kept in refrigerated condition at 7-10^{o}C in a refrigerator. Before the experiment, the skim milk had brought to ambient temperature. For this purpose, the skim milk, filled in milk can (40 L) was subjected to sprinkling of hot water, with little agitation inside the can. When the temperature of skim milk came to ambient condition, the basic material i.e. skim milk is ready for experimentation. The main experiment was conducted at intervals of 0, 1, 2 and 3 h after initial procedure and thus the total time taken for this experiment was 4 to 5 h. Different chemical tests such as fat, SNF and total solids content were carried out before experiment.

Chemical composition of skim milk

The chemical compositions of skim milk have shown slight variation depending upon various parameters like weather, time of milking etc. The variations of various constituents are given in following table 1.

Apparatus used in experiment

Hydraulic Bench

Hydraulic bench is a self-contained, compact hydraulic flow table useful for determining hydraulic and flow parameters by testing various experimental set-ups in a hydraulic laboratory (Fig. 1). It consists of a sump tank (90 L), measuring tank (60 L), pump set and associated piping and is fitted with fibre glass bench top as working area. Skim milk delivered to the experimental setup by a motorized pump set through bench mounted control valve. Skim milk coming out of the set up was then directed into a funnel, which took it either to sump tank or measuring tank. Measuring tank was mounted on a frame above the sump tank. After measuring, the skim milk was allowed to discharges far specific time limits. Then after, the skim milk in this tank was released into sump tank by opening valve, which was provided at the bottom of the measuring tank. Hydraulic bench was used for the measurement of flow characteristics such as coefficient of discharge, velocity and contraction etc.

Mouthpiece apparatus

The mouthpiece apparatus consists of a measuring tank approximate size 350 mm square and 500 mm height (Fig. 2). The supply to the tank is taken through a 25 mm diameter pipe. An overflow pipe is provided at the centre of the tank, which can be raised or lowered. It helps to maintain constant head over the mouthpiece. A bridge provided above the orifice opening helps in recording X and Y coordinates of jet. The mouthpiece apparatus was connected with the hydraulic bench and used for the measurement of the flow characteristics of skim milk.

Mouthpiece

Mouthpiece is an apparatus, when fitted to an orifice, will increase the value of coefficient of discharge. The increase in value of coefficient will increase the rate of discharge through the orifice. Three types of mouthpieces are straight, diverging and converging-diverging type generally present but among these, only straight mouthpiece was used in the present investigations. That is straight mouthpiece (Fig. 3) was fixed at appropriate place. In Straight mouthpiece, the vena contracta of the jet will be formed at distance of 0.3 diameter of the mouthpiece from the connected orifice.

Experimental methods for hydraulic coefficients

Consider a tank containing skim milk at a constant level, maintained by a constant supply, as shown in Fig. 4. The skim milk flows out of the tank through an orifice, in which mouthpiece was fitted in the outside of the tank. A particle of skim milk in the jet is assumed at P. The section C-C represents the point of vena contracta.

Here,
H = Constant skim milk head
x = Horizontal distance of vena contracta along with jet of skim milk
y = Vertical distance of vena contracta along with jet of skim milk
v = Velocity of jet
t = Time taken, in seconds, by the particle to reach from vena contracta to jet of skim milk

$$y = \frac{1}{2}gt^2 \qquad \text{(i)}$$

(Where g is the acceleration due to gravity)

$$x = v\,t \text{ or } t = x/v \qquad \text{(ii)}$$

Substituting value from equation (ii) and putting in equation (i),

$$y = \frac{1}{2}gt^2 = \frac{1}{2}g\left(\frac{x}{v}\right)^2 = \frac{gx^2}{2v^2}$$

or $$v = \sqrt{\frac{gx^2}{2y}} \qquad \text{(iii)}$$

Equation (iii) was used for measurement of actual velocity. Equation (iii) is an equation of parabola. It is, thus, obvious that the path of jet is also a parabola and this equation was used for measurement of actual velocity of fluid particles. Theoretical velocity of particle,

$$v_{th} = \sqrt{2gh} \quad \text{(iv)}$$

Therefore coefficient of velocity,

$$C_v = \frac{v_{ac}}{v_{th}} = \frac{\sqrt{\frac{gx^2}{2y}}}{\sqrt{2gh}} = \frac{x}{\sqrt{4yh}} \quad \text{(v)}$$

Equation (iv) was used for measurement of theoretical velocity. The coefficient of discharge (C_d) was measured by measuring the actual quantity of discharge through the orifice in a given time t. This actual discharge may, then be divided by the theoretical discharge, which will give the required value of the coefficient of discharge.

Mathematically coefficient of discharge,

$$C_d = \frac{Q_{ac}}{Q_{th}} = \frac{Q_{ac}}{Area\ of\ orifice\ X\sqrt{2gh}}$$

The coefficient of contraction was measured by the determination of actual area of the jet at vena contracta and then dividing by the area of the orifice. Mathematically coefficient of contraction,

$$C_c = \frac{Area\ of\ jet\ at\ vena\ contracta}{Area\ of\ the\ orifice}$$

Results and Discussion

Effect of temperature and time on coefficient of velocity of skim milk

From the Fig. 5, it showed that the coefficient of velocity (Cv) of skim milk in straight mouthpiece for skim milk (at 25^{o}C of fluid temperature) decreased from 0.88 to 0.87 when time interval of experiment increased from 0 to 3 h. More or less similar trends were observed when the temperature of skim milk varied to 30 and 35^{o}C. The coefficient of velocity for skim milk is increased as the temperature of skim milk increased. It might be due to decrease in viscosity of skim milk because when the temperature of the substances increases, its viscosity decreases which contributes higher rate of flow therefore actual velocity increases. In the present investigation, the straight mouthpiece was used for the determination of coefficient of velocity. In the present set of investigation the average values coefficient of velocity were ranged between 0.87 and 0.93. Khurmi (1949) reported that value of coefficient of velocity for water in straight mouthpiece is about 0.97. The lower value of coefficient of velocity may be due to higher viscosity of skim milk than water and due to loss of head at the entrance in mouthpiece.

Table 2 revealed that the average values of coefficient of velocity of skim milk ranged from 0.88 at 25^{o}C to 0.94 at 35^{o}C and showed significant ($p \leq 0.05$) effect at each temperature. The highest and lowest values of coefficient of velocity were found to be 0.94 at 35^{o}C and 0.88 at 25^{o}C. While considering time interval of experiment, the average coefficient of velocity of skim milk ranged from 0.91 at 0 h to 0.90 at 3 h and showed non-significant ($p \leq 0.05$) difference. The highest and lowest values of coefficient of velocity were found to be 0.91 at 0 h and 0.90 at 3 h.

From this analyzed data, it was observed that the effect of temperature showed significant effect but the time and combined effect of temperature and time did not show any effect on coefficient of velocity of skim milk.

When fluid passes through any narrow restriction, it causes variations in flow properties. The velocity of flow dependent upon cross sectional area available for flow. In such cases velocity of skim milk is directly proportional to the coefficient of velocity, depending upon this coefficient of velocity the pipe diameter and length of pipe also can be decided.

Effect of time and temperature on the coefficient of discharge of skim milk by discharging through a straight mouthpiece

From the Fig. 6, it showed that the coefficient of discharge for skim milk (at 25°C of fluid temperature) decreased from 0.68 to 0.65 when time interval of experiment increased from 0 to 3 h. More or less similar trends were observed when the temperature of skim milk varied to 30 and 35°C. It may be due to increase in viscosity with increase in time, which is taken in the present investigation

The coefficient of discharge increased, as the temperature of skim milk increased because when the viscosity of the substances decreases actual discharge increases and vice versa. Actual discharge is directly proportional or related to the coefficient of discharge. Higher value of C_d was obtained at 35°C temperature, because in this temperature the viscosity of skim milk must have been decreased. The average coefficient of discharge obtained from present investigation ranged from 0.66 to 0.76 for straight mouthpiece. This higher value was made possible by fitting an external mouthpiece.

Steffe and Salas-Valerio (1990) conducted experiments on discharge through orifices. They studied the effect of the rheological properties of non-Newtonian (power law) fluids on C_d. They reported that the discharge coefficient was within the range of 0.6-0.7. This was dependent on the orifice diameter, fluid velocity and rheological properties. They also found that C_d decreases as the consistency coefficient increases.

Table 3 showed that the average values of coefficient of discharge ranged from 0.66 at 25°C to 0.77 at 35°C and showed significant ($p \leq 0.05$) effect at and above 25°C. Similarly, while considering time interval of experiment, average coefficient of discharge value ranged from 0.72 at 0 h to 0.69 at 3 h and showed statistically significant ($p \leq 0.05$) effect at and above 0 h.

Table.1 Chemical analysis of skim milk

Constituent	**Fat**	**SNF**	**Total Solids**	**Titratable acidity**
Value (%)	0.5-0.7	8.4-8.75	9.06-9.66	0.14-0.16
Average ± S.D.	0.57 ± 0.1	8.59 ± 0.15	9.43 ± 0.34	0.15 ± 0.01

Table.2 ANOVE for effect of time and temperature on the coefficient of velocity

Parameter	**SEm**	**F cal**	**CD**	**CV (%)**
T	0.002	344.306*	0.005	0.82
h	0.002	4.061	0.006	
Txh	0.003	0.262	-	

Table.3 ANOVE for effect of time and temperature on the coefficient of discharge

Parameter	SEm	F cal	CD	CV (%)
T	0.002	804.839*	0.005	1.04
h	0.002	28.966*	0.006	
Txh	0.004	0.287	-	

Table.4 ANOVA for effect of time and temperature on the coefficient of contraction

Parameter	SEm	F cal	CD	CV (%)
T	0.003	153.909*	0.008	1.28
h	0.003	7.052	0.009	
Txh	0.005	0.574	-	

Fig. 1 Hydraulic bench

Fig. 2 Mouthpiece apparatus

Fig.3 Line diagram and view of straight mouthpiece

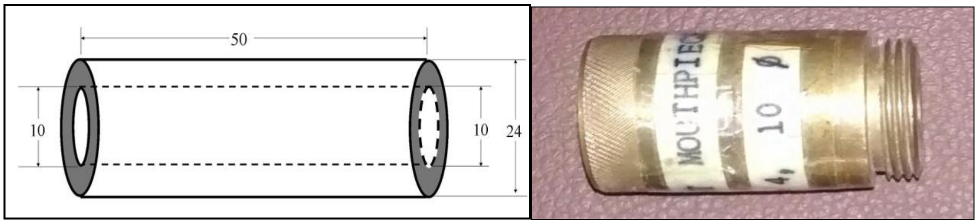


Fig.4 Experimental method of hydraulic coefficient measurement

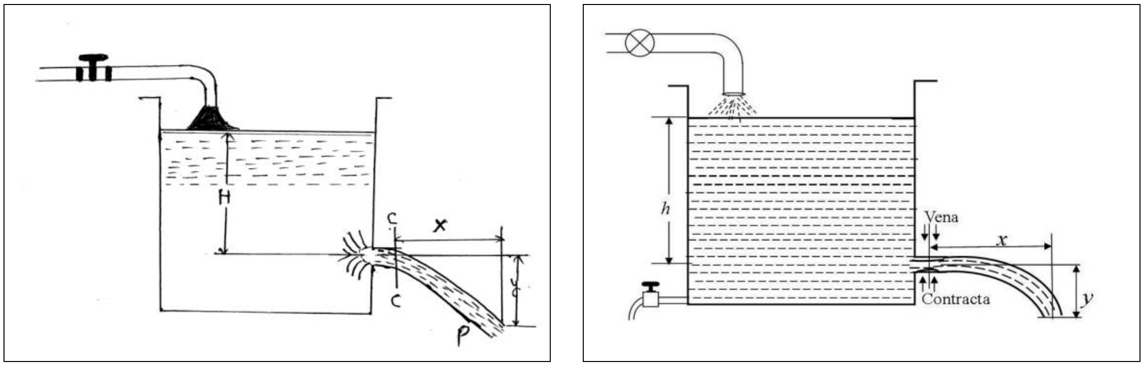


Fig.5 Effect of time and temperature on coefficient of velocity

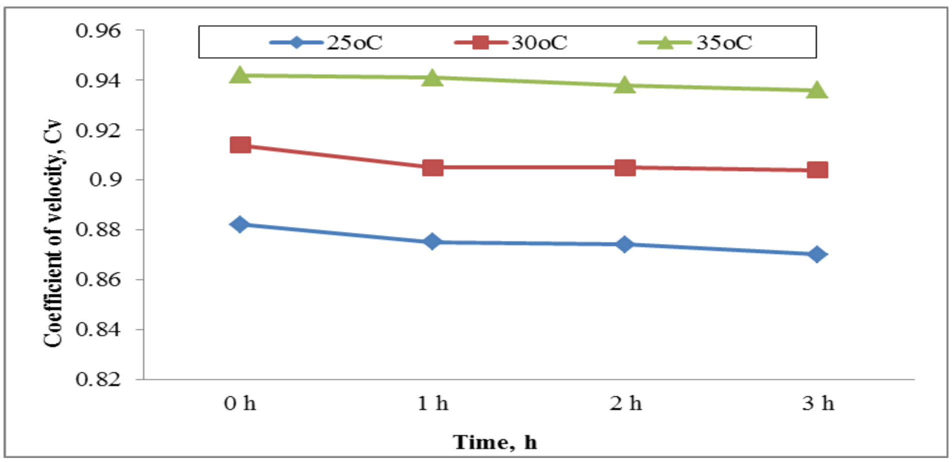


Fig. 6 Effect of time and temperature on the coefficient of discharge

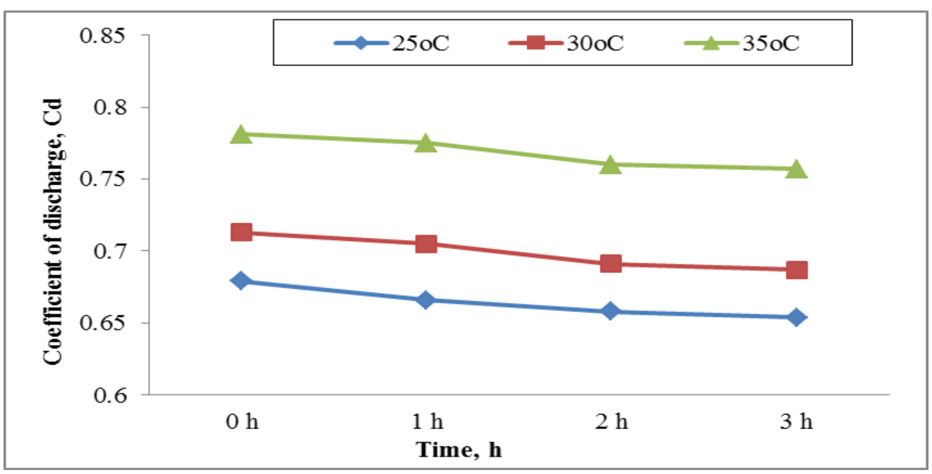
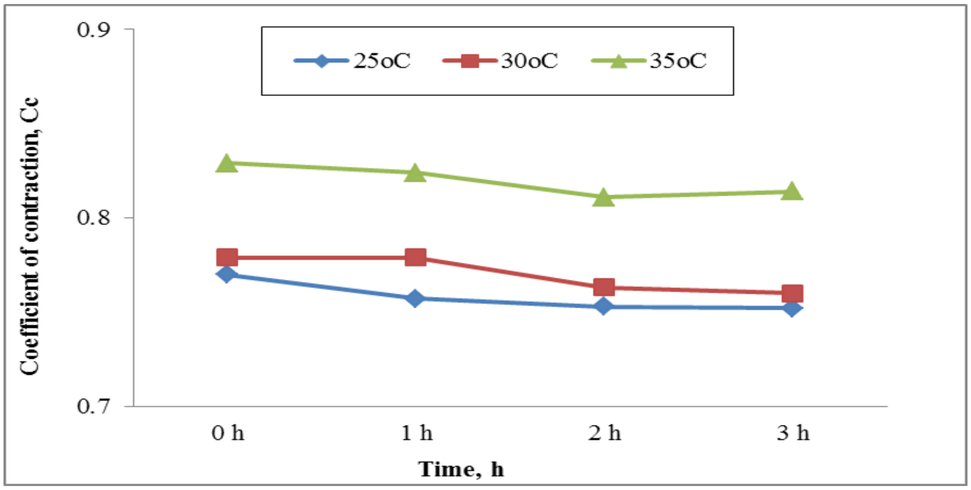


Fig.7 Effect of time and temperature on coefficient of contraction



From this ANOVA table, it was observed that the temperature and time showed significant effect but the combined effect of temperature and time did not show significant effect. By connecting mouthpiece increase the coefficient of discharge and reduce the loss of energy of skim milk while formation of vena contracta while emptying tanks. The vena contracta will be formed in mouthpiece. By connecting mouthpiece reduce the time of discharge at emptying the skim storage tanks and at skim milk road tanker also.

Effect of time and temperature on the coefficient of contraction of skim milk by discharging through a straight mouthpiece

From the Fig. 7, it showed that the coefficient of contraction for skim milk (at 25^{o}C of fluid temperature) decreased from 0.77 to 0.75 when time interval of experiment increased from 0 to 3 h. More or less similar trends were observed when the temperature of skim milk varied to 30 and 35^{o}C. The coefficient of contraction for skim milk increased as the temperature of skim milk increased. Higher temperature and thereby lower viscosity resulted in increases velocity and cross sectional area of jet at vena contracta. These factors may be responsible for increase in coefficient of contraction of skim milk. Smith and Walker (1923) have found the Values of C_c to be about 0.67 for a 2 cm orifice and 0.614 for a 6 cm orifice, for heads that are greater than 1.2 m. The value of C_c increases as head values decrease, to as high as 0.72 for a 2 cm orifice less than 6 cm of head. The coefficient of contraction can be increased by increasing the roughness around the orifice and by rounding the inner edge of the orifice. The values obtained for C_c in the present study 0.59-0.79 and these are in accordance with these references.

Table 4 showed that the average coefficient of contraction ranged from 0.76 at 25^{o}C to 0.82 at 35^{o}C and showed significant ($p \leq 0.05$) effect. Similarly, while considering time interval of experiment, the average coefficient of contraction ranged from 0.79 at 0 h to 0.78 at 3 h and between 1 h and 2 h showed significant effect but did not show significant effect between 0 h and 1 h, 2 h and 3 h.

From the analyzed data, it was observed that the effect of temperature showed significant effect but time and combined effect of temperature and time did not show significant effect on coefficient of contraction of skim milk. By measuring the coefficient of contraction, can analyze the sharpness of orifice which is connected for discharging the skim milk from the storage tanks, if the coefficient of contraction value is low it means the sharpness of the orifice is high then simultaneously the discharge of skim milk also reduces.

In conclusion, the present investigation was carried with the objectives to have insight on variation of some physical properties of skim milk with time and temperature. The density of skim milk decreased 1032.32 to 1028.29 kg/m^3 when temperature of skim milk increased from 25 to 35^{o}C. Similarly, when time of experiment interval increased from 0 to 3 h, it increased from 1030.21 to 1030.99 kg/m^3. The specific weight of skim milk decreased from 10.13 to 10.09 kN/m^3 when temperature of skim milk increased from 25 to 35^{o}C. Similarly, when the time interval of experiment increased from 0 to 3 h, it also increased from 10.11 kN/m^3 to 10.12 kN/m^3. The electrical conductivity of skim milk increased from 5.41 to 5.62 mS/cm when temperature of skim milk increased from 25 to 35^{o}C. Similarly, when the time interval of experiment increased from 0 to 3 h, it also increased from 5.47 to 5.54 mS/cm.

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